it might have been supposed that the flexor after-discharge remained unimpaired after withdrawal of the crus stimulus. But this is not the case. Immediate relaxation of flexor contraction occurs just as in a "pure" crus reaction. To this extent the crus flexion reaction seems to be antagonistic to the flexion reaction of the after-discharge in the dorsal focal point reaction. The non-postural cerebral activity seems to abolish the postural mid-brain activity and thus to leave, perhaps, a virgin field for any subsequent reaction.

Synthesis by Sunlight in Relationship to the Origin of Life. Synthesis of Formaldehyde from Carbon Dioxide and Water by Inorganic Colloids acting as Transformers of Light Energy.*

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At a discussion on the origin of life held by the joint sections of Zoology and Physiology of the British Association, at the Dundee Meeting, September, 1912, it was suggested by Moore that the first step towards the origin of life must have been the synthesis of organic matter from inorganic by the agency of inorganic colloids acting as transformers or catalysts for radiant solar energy. This suggestion was amplified and explained in a book written in November, 1912, by the same author.†

It is important to emphasise the point that in considering the origin of life in a world containing inorganic matter only, the nutrition of the first living structure on such a world must be carefully borne in mind. This observation is still true whether life is to be regarded as arising *de novo* on the planet, or as being borne there from some other planet as a germ from pre-existent life. No living organism such as a bacterium or mould which did not possess the power of transforming energy and of synthesising organic

from inorganic matter could exist or flourish in total absence of pre-formed organic matter and must inevitably perish.

A substance acting as a transformer of light energy with accompanying synthesis of organic from inorganic matter now exists in our world, in chlorophyll, the green colouring matter of plants, and also allied bodies such as the blue-green colouring matter of the Cyanophyceæ possess a similar power. But both these substances are exceedingly highly organised and complex, quite unsuitable by their nature to be thought of as the first stage in the evolution of organic from inorganic matter at the dawning of life in a world hitherto devoid of anything organic.

The protoplasm of the living cell also is built up of the most complex organic compounds known to us such as could scarcely arise in an entirely inorganic world as the first step from inorganic to organic matter.

The first primeval step would appear to be indicated by the union of single crystalloidal inorganic molecules to form inorganic colloids, and that these meta-stable colloids acting on inorganic carbon compounds, such as carbon dioxide, in presence of water and sunlight, and taking energy from the sunlight, built up at first simple organic bodies, and now these in turn reacting with one another formed more and more complex organic compounds. In any such transformation external energy is necessary, because the reacting bodies, carbon dioxide and water, are fully oxidised, and must be reduced with evolution of oxygen and uptake of energy in what is called an endothermic reaction. To this reaction, the inorganic colloid plays the part of an activator or catalyst, the solar energy being converted into chemical energy of the organic compound, so serving as a reservoir of the energy necessary for the coming living organic world.

It was first suggested by Baeyer[*] that the initial stage in the synthesis of organic matter from inorganic by the green plant consisted in a reaction of carbon dioxide and water to produce formaldehyde and oxygen, the energy for the endothermic reaction being supplied from the energy of the light vibrations. This has been confirmed by delicate reactions, for although the change is a transitory one, the formaldehyde being condensed into other organic substances as it is formed, yet colour reactions for aldehydes are known so delicate that they will clearly indicate 1 part in 1,000,000 of aldehyde.

Any accumulation of formaldehyde would rapidly kill the living cell, and it is soon transformed into other products, but the colour tests are so delicate that its presence in traces has now been confirmed by several observers.[†]

[*] 'Berichte d. deut. chem. Gesellsch.,' 1870, vol. 3, p. 68.

[†] See especially, Usher and Priestley, 'Roy. Soc. Proc.,' 1906, B, vol. 77, p. 369, where references to other papers are given.

Acting on the hypothesis outlined above, experiments with a view to testing the synthetic action of sunlight in presence of inorganic colloids were commenced by us in November, 1911, but for over a year only negative results were obtained, on account of difficulties in adjusting proper concentrations of solution, securing adequate illumination in vessels made of suitable material, and obtaining delicate enough methods for separating and identifying formaldehyde. After overcoming these experimental difficulties, and with the aid of the brighter sunshine, a large number of positive results have been obtained, within the past few weeks, and the synthesis of formaldehyde under the conditions to be described below has been shown quite unmistakably by all the usual colour-reactions for formaldehyde.

It has also been shown that it is the ultra-violet rays which are most effective. The use of quartz flasks as containers for the colloid gives, with the same intensity of insolation, definite results in a much shorter period, and lately we have found that a "Uviol" mercury arc, in a "Uviol" glass protecting vessel, immersed in an outer wider cylinder of glass so as to produce a thin layer of the colloid, through which the carbon dioxide is passed, gives quite clearly positive reactions for formaldehyde by all the colour tests, with an exposure to light of only four or five hours.

The results are obtained either with colloidal hydrated ferric oxide, or colloidal oxide of uranium, in exceedingly dilute solution. For example, in the case of uranium, 0·028 per cent. of the oxide, and, in the case of the iron, 0·113 per cent. of ferric oxide were the concentrations used.

Controls carried out in the absence of light gave no formaldehyde, and all precautions were taken to exclude contamination in any way. The same point is shown by our earlier unsuccessful experiments in which the illumination was inadequate.

Formaldehyde in small amounts has already been synthesised from inorganic sources in several reactions in which hydrogen in the nascent condition, or adsorbed in palladium, has been present. But there is here chemical energy as such, presented by the hydrogen, and so far as we are aware there is no case known of utilisation of light energy by an inorganic catalyst which does not itself become altered in the reaction.

Thus Bach[*] obtained formaldehyde from hydrogen-palladium and carbon dioxide, Fenton[†] obtained it by the action of carbon dioxide and water on metallic magnesium, and other observers have obtained it by the interaction of dilute sodium amalgam and moist carbon dioxide.

The only experiment approaching more closely to our own as recorded

[*] 'Comptes Rendus,' 1898, vol. 126, p. 79.
[†] 'Journ. Chem. Soc. Trans.,' 1907, vol. 91, p. 687.

below is one devised by Bach,* and later repeated with modifications by Euler† and by Usher and Priestley.‡

Bach passed a current of carbon dioxide through a solution of 1·5 per cent. *crystalloidal* uranium acetate, and in the presence of light obtained a precipitate of mixed oxides of uranium, which did not occur when light was excluded during the passage of the carbon dioxide. He adduces no direct experimental evidence of the presence of formaldehyde in the solution, but makes the hypothesis that the carbonic acid by the action of light forms formaldehyde and per-carbonic acid. Then the per-carbonic acid decomposes and forms peroxide of uranium. Lastly, the formaldehyde attacks uranic oxide forming lower oxides recognisable by their colour in the precipitate of mixed oxide. In confirmation he shows that when peroxide of uranium and actually added formaldehyde are exposed to sunlight a reduction to lower oxide occurs with production first of a green and then a violet colour.

It will be observed, first that the crystalloidal salt of uranium employed undergoes permanent change, and secondly that there is no clear evidence of formation of formaldehyde, although our experiments recorded below show that Bach's hypothesis is probably a correct one. All the experiment actually proves, however, is that acetate of uranium in crystalloidal solution, in presence of carbon dioxide and sunlight, is decomposed, yielding a mixture of oxides of uranium. At the same time it is an important pioneer experiment in this field.

In a later experiment, Bach obtained evidence of the formation of formaldehyde by exposing to light a solution of dimethylaniline in dilute sulphuric acid through which carbon dioxide was passed. There is here, however, the objection of using an organic body as catalyst, although the reaction is interesting as a photo-synthesis.

The same objection holds, as to the presence of the acetic acid anion in the uranium acetate solution used above, since this might serve as a source of formaldehyde.

A considerable increase in our knowledge was given in the papers of Usher and Priestley quoted above, in which they repeated and extended Bach's experiment.

The experiments of Bach were repeated and confirmed by these authors, both as to the production of peroxide and formaldehyde. The amount of decomposition obtained in three weeks in bright weather was extremely small, and this was ascribed to the poorness of the uranium as a catalyst, and

* 'Comptes Rendus,' 1893, vol. 116, p. 1145.

† 'Berichte d. deut. chem. Gesellsch.,' 1904, Jahrgang 37, vol. 2, p. 3411.

‡ 'Roy. Soc. Proc.,' 1906, B, vol. 77, p. 369 ; and 1906, B, vol. 78, p. 322.

the non-removal of the separated oxygen which remained as uranium peroxide and acted as a destructive agent upon the formaldehyde.

The authors accordingly took tubes of Jena glass, cooled them in liquid air, passed in carbon dioxide, sealed, and exposed for 24 hours, suspended outside a south window, in bright sunlight. A precipitate appeared after 15 minutes' exposure, and in 24 hours the reaction was complete. The tubes on opening were found to contain uranium peroxide and formic acid, but no formaldehyde.

Usher and Priestley then repeated their experiments using uranium sulphate instead of the acetate. Carbon dioxide was passed through a 2-percent. crystalloidal uranium sulphate solution, and the solution was exposed to sunlight on a roof for nearly a fortnight. Several grammes of a precipitate of mixed oxides of uranium were obtained of a pale violet colour. The greater part was a mixture of uranous and ordinary uranic hydroxides soluble in acetic acid. The insoluble residue was a hydrate of uranium peroxide. The filtrate from all these mixed hydroxides was distilled and examined for formaldehyde. None, however, was found, though the liquid reduced Fehling's solution and silver nitrate. It was subsequently found to contain formic acid, the lead salt of which was prepared and identified. The undistilled residue was then evaporated down, and when nearly solid was repeatedly extracted with dry ether in order to remove any formic acid which had not evaporated. The residual solid was extracted with absolute alcohol, and the solution on evaporation left a small quantity of a brown syrup, bitter to the taste, which reduced Fehling's solution. It could not be proven that this formed an osazone, but it closely resembled in its properties a substance called "methylenitan" obtained by Butlerow from formaldehyde and milk of lime. The body was obtained in minute amount only.

This experiment constitutes a distinct advance, since the organic substances (formic acid and the body above mentioned) were obtained by the action of light on purely inorganic substances.

The points still left against the results, from the aspect mentioned at the outset of the present paper, are that the catalyst is an extremely rare one in nature, that it was used in high concentration in crystalloidal solution, and that it underwent changes in itself and was precipitated as the result of the reaction. The fact that formic acid was obtained instead of formaldehyde, looked at from our point of view, is relatively unimportant, since both are organic bodies of increased energy content.

By the use of many times more dilute colloidal uranic hydroxide, we have been able now to obtain formaldehyde, and this without precipitation or other visible change in our catalyst. Compared with a stronger solution of

crystalloidal uranium nitrate alongside, and given the same exposure and general conditions, we have been able to show that the colloidal condition is much more active in this photo-chemical reaction. In this comparative experiment the crystalloidal uranium nitrate was precipitated while no precipitation whatever occurred in the colloidal uranic hydroxide.

Passing on, we have shown that similar photo-synthesis of organic from inorganic matter easily occurs with colloidal ferric hydroxide, and by the use of the "Uviol" mercury lamp we are enabled to experiment at all times and obtain synthetic results readily in a few hours, a consideration of some importance in working in a country where sunlight is so variable, and so often unavailable for days.

The experiments with uranic hydroxide and ferric hydroxide were made concurrently in time, but for convenience we shall describe first the uranium experiments and then those with the ferric hydroxide.

Photo-synthesis by Colloidal Uranic Hydroxide.

Method of Preparation of the Colloidal Solution.—A strong solution of uranium nitrate (approximately 10 per cent.) is taken and treated in the cold by adding a saturated solution of ammonium carbonate until the precipitate just ceases to re-dissolve. The solution is then filtered and dialysed in a tube of parchment paper for several days against running water. The greater part of the uranium is still in the crystalloidal state, and dialyses away at this stage. Great care is required in the first step to get the proper relative amount of ammonium carbonate; also it is as well not to wait for the removal of the last traces of crystalloidal uranium, but to take the solution when it still gives a faint reaction with potassium ferrocyanide. The amount so left is, however, very minimal compared with the crystalloidal uranium solutions as used in the experiments recorded below, and nearly all the uranium at the end is present as colloidal uranic hydroxide.

This method is practically the same as that described by Graham for the preparation of colloidal ferric hydroxide and as used in the preparation of our colloidal iron solutions.

The amount of uranium in this solution was determined by evaporating a measured volume to dryness and weighing the residue, and was found to be 0·478 per cent. of Ur_2O_3.

In carrying out the photo-synthetic experiments this solution was either diluted 15- to 20-fold with distilled water and carbon dioxide, evolved from marble and pure hydrochloric acid and washed by water in a wash-bottle, passed through in a slow stream, or it was diluted to the same degree with distilled water previously saturated with carbon dioxide and sealed up

hermetically in glass tubes, which were then exposed to such direct sunlight as was available on the flat roof of the laboratory.

It will accordingly be observed that the concentration of the colloidal uranic hydroxide in the solutions actually exposed to the light was only 0·024 to 0·035 per cent. The stock solution of the colloid had a pale lemon yellow colour, and the diluted solutions were almost colourless, showing just the merest trace of yellow colour, and the solutions throughout remained water clear. The colloidal solution is very sensitive, and is precipitated by traces of added crystalloid.

The test solution for aldehyde used in our earlier experiments was Schiff's reagent, which consists of a dilute solution of fuchsin (about 1 per cent. in water) through which sulphur dioxide is passed until it is just decolorised. This reagent added in the proportion of 3 drops to 10 c.c. of a dilute formaldehyde solution shows the presence of the latter by a distinct pink coloration, developing in about half an hour at a dilution of 1 in 500,000.

At a later stage our observations were confirmed by the Mulliken and Schryver tests.

Mulliken's test, as used by us, consists in adding two drops of a 3-per-cent. solution of gallic acid in absolute alcohol to 6 c.c. of strong sulphuric acid in a test-tube, and then pouring on the surface of this mixture 2 c.c. of the solution suspected to contain formaldehyde, when a light blue coloured ring develops at the junction and gradually penetrates the sulphuric acid.

Schryver's test was carried out by preparing a 5-per-cent. solution of potassium ferricyanide and a 1-per-cent. solution of phenylhydrazine hydro-chloride which was used as follows:—To 10 c.c. of the solution suspected of containing formaldehyde 2 c.c. of the phenylhydrazine solution is added, then 1 c.c. of the potassium ferricyanide solution followed by 3 c.c. of concentrated hydrochloric acid, when a pink coloration appears. If this is diluted with water it becomes colourless, this colourless solution is shaken with ether, and the ethereal solution which is not coloured is separated off. Finally the ethereal solution is shaken up with a few cubic centimetres of concentrated hydrochloric acid, when, if formaldehyde be present, a strong pink or carmine colour appears in the hydrochloric acid layer.

All three of these colour tests for formaldehyde have been obtained on many occasions.

Experiment I.—20 c.c. of dilute colloidal uranic hydroxide solution contain-ing approximately 0·03 per cent. of Ur_2O_3 was placed in a test-tube on the roof, and carbon dioxide generated in a Kipp, and washed as above described, was slowly bubbled through. The day was a bright sunny one (May 26,

1913) and the experiment was continued all day. Half of the solution was taken out, and of this the greater part was distilled off from the colloid. Tested with Schiff's reagent this distillate gave a distinct pink coloration within half an hour. The remaining half of the colloidal solution was kept on the following day, which was also a bright sunny day, on the roof with carbon dioxide bubbling slowly through it, it was then tested in the same way for aldehyde, and gave a still stronger reaction. Blanks were carried out with distilled water and the Schiff's reagent and the contrast was most marked, the distillate from the colloid exposed to light giving a deep pink, while the distilled water control remained colourless.

Experiment II.—Thirty c.c. of the same dilute colloidal uranium solution was taken in a wide test-tube, saturated with carbon dioxide by bubbling the gas through, and then hermetically sealed. The tube was left resting on its side on the roof for two days, both of which had a good deal of bright sunshine. The contents of the tube showed no visible alteration or precipitation at the end of the period. The tube was now opened and about two-thirds of its contents were distilled off. The distillate tested with Schiff's reagent gives a marked formaldehyde reaction.

Experiment III.—A soda-water syphon with a "sparklet" apparatus for charging with CO_2 was taken, and in it were placed 500 c.c. of distilled water, 30 c.c. of the stock colloidal uranium hydroxide solution, giving accordingly a concentration of 0.035 per cent. of Ur_2O_3.

This was charged with carbon dioxide from a "sparklet" bulb, and left on the roof for 13 days, of which 7 were bright days with strong sunlight. At the end of the period a portion was withdrawn and distilled. It gave strong positive reactions for formaldehyde with both Schiff's reagent and Schryver's test.

The stock solution of colloidal uranium hydroxide diluted equally and distilled without previous exposure to light gave negative results in both tests.

Experiment IV. Contrast of Action of Colloidal Uranium and Crystalloidal Uranium.—Two glass tubes were taken of similar dimensions; in the first were placed 20 c.c. of distilled water saturated with carbon dioxide from a "sparklet" syphon, and 2 c.c. of stock colloidal uranium hydroxide solution; in the other tube, 20 c.c. of the water charged with carbon dioxide from the same syphon and 0.2 c.c. of 20-per-cent. crystalloidal uranium nitrate solution. At the end of the experiment, by drying and incinerating a measured volume, the percentage of uranic oxide was determined, and it was found that the colloidal solution contained 0.041 per cent., and the crystalloidal 0.08 per cent., so that the crystalloidal solution was approxi-

mately double in concentration that of the colloidal. The two tubes were hermetically sealed and placed on the roof for six days, three of which had bright sunshine, the others very cloudy and raining. The two tubes were opened, and the contents separately distilled in a similar fashion. The distillate from the crystalloid showed negative results with the Schiff's test. while the distillate from the colloid gave a most strongly marked positive reaction.

Experiment V. Illustrating the Necessity for Strong Direct Sunlight.—Two solutions, one of colloidal uranic oxide, the other crystalloidal uranium nitrate of approximately equal concentration, were taken, of each 50 c.c., in a glass tube, and washed carbon dioxide was bubbled through each in a slow stream. These were exposed on the roof for two days. Both these days were dull with practically no sunshine; there was, however, fairly bright diffuse daylight. The contents were then distilled as in the preceding experiments, but negative results were obtained in both cases.

Experiment VI.—Four similar wide glass tubes were taken, and into each was introduced 30 c.c. of distilled water charged previously with carbon dioxide, and 2 c.c. of colloidal uranic oxide solution, containing 0·478 per cent. of Ur_2O_3. Accordingly, the concentration of colloid in each case was approximately 0·03 per cent., or 3 in 10,000 parts. The four glass tubes were then sealed up hermetically and treated as follows :—

1. The first tube was exposed on the roof to such sunlight as was available for six days, in four of which there was brilliant sunshine all day.

2. The second tube was preserved for the same period in a dark cupboard in the laboratory.

3. The third tube was immersed in a wider open glass tube containing a strong alcoholic solution of chlorophyll, so as to give a chlorophyll shade all round it, between it and the sunlight, and then the open tube was closed by a cork. This tube was then, thus sheathed, exposed to the sunlight on the roof alongside the first tube and for a similar period.

4. The fourth tube was immersed in a 5-per-cent. solution of quinine sulphate in a similar manner to that described for tube No. 3, and was then exposed in like manner to Nos. 1 and 3, and for the same period.

The contents of the four tubes were distilled off in each case, and the four distillates were comparatively tested alongside one another, using the Schiff's and Mulliken's tests.

The tube kept in the dark gave completely negative results, while all three exposed to the light (Nos. 1, 3, and 4) gave positive results; the tube surrounded by chlorophyll (No. 3) was the strongest, and next was that surrounded by the quinine solution, both being more marked than the tube

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exposed to direct sunlight. But much more experimentation is required here. There is, however, no doubt that active rays penetrate both chlorophyll and quinine solutions, as the reactions were most distinct, and it appeared as if these solutions possibly had prevented the passage of rays with a slowing effect on the reaction.

Experiment VII. Dilute Colloidal Uranic Oxide Solutions Exposed to Light from a " Uviol" Mercury Arc in a Transparent Quartz Test-tube.—40 c.c. of a colloidal uranic oxide solution made by diluting the stock solution 15-fold, and so containing 0·03 per cent. of the colloid, were placed in a tube of transparent quartz, and after saturation with washed carbon dioxide from a Kipp apparatus were exposed about $2\frac{1}{2}$ inches from a " Uviol " mercury arc for the period during three days in which the lamp was lit, probably about 12 hours in all. At the end of the period the fluid was distilled and the distillate tested by Schryver's test. It gave a strongly marked reaction, corresponding to at least 1 part in 100,000 of formaldehyde.

Photo-synthesis by Colloidal Ferric Hydroxide.

Preparation of Colloidal Solution.—The colloidal ferric hydroxide solution was prepared after the method originally given by Graham.* A strong solution of ferric chloride is taken, about 20 per cent., and to this a saturated solution of ammonium carbonate is added gradually with shaking so long as the precipitate first formed continues to dissolve. The solution is then dialysed for some days, 10 days or more, until the reaction for chloride becomes very faint. The solution so obtained is of a deep reddish brown colour, even in a 1-per-cent. solution, and if converted back into the crystalloidal form by boiling with a drop or two of acid the change is remarkable, to a pale lemon yellow colour. At the dilutions used in the experiments below the colour scarcely shows when reduced to the crystalloidal condition, but in the colloidal condition, even at this dilution, the solutions possess a deep sherry colour. The dilute solution in an ordinary small test-tube absorbs the blue of the spectrum completely, as shown by a pocket spectroscope. When viewed by light transmitted from a " Uviol " mercury lamp, the solution viewed directly transmits a yellowish green light, and at the sides, reflected from the glass surfaces, there is a deep green fluorescence, which reminds one strongly of the fluorescence of a strong solution of chlorophyll.

The colloidal iron solution so prepared is readily coagulated by boiling, and is most sensitive to added crystalloids; it is thrown out by 1 part in

* 'Phil. Trans.,' 1861, vol. 151, p. 208.

1000 of ammonium carbonate, and a mere trace of deci-normal caustic soda throws it completely down. It is in a delicately reactive metastable condition, which reminds one forcibly, as it did Graham 50 years ago, of the proteins and the constituents of living cells.

When set up in the "Uviol" apparatus and the transmitted light observed with a spectroscope, it is seen that the bright lines of the mercury arc spectrum in the blue and violet have entirely disappeared, and the only ones now visible are those of the red, orange, and green. An examination of the solar spectrum shows complete absorption of all higher wave-lengths than green.

There is this difference between the solar and the mercury arc light absorption, that in the former there is a continuous spectrum absorbed from green onward, while in the mercury arc spectrum the absorption is that of three sets of wave-lengths, one at the junction of green and blue, the other far over in the blue, and the third in the violet portion of the visible spectrum. We have not hitherto been able to observe the absorption of the ultra-visible rays. The light energy from these definite wave-lengths of the spectrum seems, however, from the results recorded below, to be very effective for the particular synthesis under consideration.

In describing the synthetic results with the ferric oxide colloid, a few earlier experiments made in glass vessels with rather poor daylight illumination may be passed over, merely remarking that these led us on to the others in which unmistakable evidence of organic synthesis was obtained, and only the latter are here recorded. With sufficient illumination either with sunlight or the mercury arc spectrum, and especially when "Uviol" glass or quartz has been used, we have never failed to obtain clear evidence of synthesis.

Experiment I.—A dilute solution of colloidal ferric hydroxide containing 0·2 per cent. of Fe_2O_3, was placed in a thin blown flat-sided glass bottle, made like a wash-bottle with ground glass stoppers. A slow current of carbon dioxide, washed by passing through a wash-bottle containing water, after evolution from marble in a Kipp apparatus, was passed through the colloidal solution during two days of fairly bright sunshine on the laboratory roof. On distillation this gave a moderately strong positive reaction to the Schiff's test.

Experiment II.—A glass soda-water syphon with a "sparklet" apparatus attached was charged with 500 c.c. of distilled water and 5 c.c. of a colloidal ferric oxide solution, and after dilution contained about 0·05 per cent. of colloidal ferric oxide. This was saturated with carbon dioxide by a sparklet bulb, and left on the roof for a period of 20 days, in which there were about

13 days of bright sunshine. At the end of the period, 40 c.c. were withdrawn and distilled. A very distinct positive reaction for formaldehyde was obtained with Schryver's test.

Experiment III. Exposure to Sunlight in Transparent Silica Flask.—A colloidal solution of ferric hydroxide of a concentration of 0·14 per cent., measuring 50 c.c., was placed in a silica flask through which carbon dioxide was passed, on the roof. The experiment lasted for two days, of which the first was dull, and the second almost continuous bright sunshine. On distillation this gave a most marked positive reaction with Schiff's test, indicating from the short period of exposure that the reaction probably proceeds more rapidly in silica vessels which are more transparent to the shorter wave-lengths of light.

Experiment IV. Exposure to Mercury Arc Lamp with Uviol Glass Shade.—A colloidal solution of ferric hydroxide diluted 1 in 20 from a stock solution of 2·26 per cent., and hence containing 0·113 per cent. of colloid, was placed in a wide 1000 c.c. measuring cylinder. In this glass cylinder was immersed a wide round-bottomed tube of " Uviol " glass of somewhat smaller diameter to serve as a protector between the heated lamp to be placed in the interior, and the surrounding fluid between the " Uviol " tube and the outer cylinder of glass. The mercury lamp was then set going, and inserted in the centre of the " Uviol " glass protecting tube. The mercury lamp tube, also of " Uviol " glass, had a diameter of 3 cm. approximately, the protecting tube a diameter of 5·4 cm. externally, and the outer glass cylinder an internal diameter of about 6·2 cm. The light generated at a distance of about 2 cm., after passing two thicknesses of " Uviol " glass and a layer of air of somewhat less than a centimetre, passed through a layer of the colloidal solution about 4 to 5 mm. thick and then reached the outer glass vessel. On account of the rounded bottom of the " Uviol " protecting tube there was a certain considerable volume of the solution at the bottom not so well illuminated. The total volume of colloidal solution at the bottom and in the annular space between the two tubes was approximately 300 c.c.

A slow steady stream of washed carbon dioxide was passed through the colloidal solution.

After about half-an-hour's running the colloidal solution became too warm and began to coagulate, so the current was switched off and the lamp allowed to cool. The whole was then immersed in a wide square-sided glass jar of about 17 litres capacity through which a stream of cold water was continuously circulated. The lamp was now re-lit and kept going for a period of 2 hours, making $2\frac{1}{2}$ hours of illumination in all. In this first experiment with the " Uviol " apparatus, the colloidal solution had coagulated at the end

but this did not happen in later experiments when the heat was better regulated.

The colloidal solution was removed and tested for formaldehyde in two ways. One portion was distilled as in the previously recorded experiments and the distillate gave a most marked positive reaction with Schiff's reagent —a deep pink coloration. A second part was simply filtered off from the coagulated iron precipitate, and at once tested. It also gave a marked positive reaction both with Schiff's and Mulliken's tests.

Experiment V.—An experiment of the same type as the preceding one. A colloidal solution of 1 in 20 of the same stock solution was taken, and exposed to the mercury arc light as before. Illuminated during two periods of 55 minutes and 2 hours 50 minutes, respectively, making 3 hours 45 minutes in all. Part of the solution distilled off gives a distinct positive reaction with Schiff's test. Another portion coagulated by boiling, and filtered from iron, but not distilled, gives a positive reaction with gallic acid and concentrated sulphuric acid (Mulliken's test).

The experiment was continued next day from 10.15 A.M. till 2.15 P.M.; at the end of this 4 hours' period the solution coagulated, owing to a failure in the water circulation and the temperature rising. The coagulated fluid was filtered and the filtrate tested, it gave a marked positive effect with Schiff's test and also a positive result with Mulliken's test, a trace of iron left over interfered with the Schryver test, but on distillation this also was obtained.

Experiment VI.—This was conducted similarly to the above experiments IV and V for a period of 1 hour and 40 minutes. Then a trace of ammonium carbonate amounting to only 1 part in 1000 was added with the view of forming hexamethylenetetramin and so concentrating the formaldehyde, but even this trace coagulated the solution.

The experiment was, however, continued for $5\frac{1}{2}$ hours additional. A small portion was acidified and distilled. The distillate gave a marked positive reaction with Schryver's test.

Experiment VII.—A dilute colloidal solution of ferric hydroxide (1 in 15) of stock solution, equivalent to 0·13 per cent. of ferric oxide, was exposed after saturation with carbon dioxide, in a silica test-tube 3 inches away from the mercury arc, during the time the lamp was lit on three days, probably about 12 hours in all. A most marked reaction to all tests. The reaction quantitatively is slightly less than the uranium effect, see Experiment VII of previous section, and throughout it appears that the uranium catalyst is somewhat more powerful than the ferric catalyst.

Conclusions.

Organic matter (aldehyde) has been synthesised from inorganic colloidal uranic and ferric hydroxides in very dilute solution. These colloids act as catalysts for light energy, converting it into chemical energy in a reduction process similar to the first stage of synthesis of organic from inorganic substances in the green plant by the agency of chlorophyll.

Such a synthesis occurring in nature probably forms the first step in the origin of life. For chlorophyll and protoplasm are substances of far too complex chemical constitution to be regarded as the first step in the evolution of the organic from the inorganic.

Without the presence of organic material, when life was arising in the world, any continuance of life would, however, be impossible.

The process of evolution of simple organic substances having once begun, as now experimentally demonstrated, substances of more and more complex organic nature would arise from these with additional uptake of energy. Later, organic colloids would be formed, possessing meta-stable properties, and these would begin to show the properties possessed by living matter of balanced equilibrium, and up-and-down energy transformations following variations in environment.

There can be little question that such energy changes as are above described occur at present, and are leading always to fresh evolutions of more complex organic substances, and so towards life, and equally is it true that they must occur on any planet containing the necessary elements for the evolution of inorganic colloids and exposed to light energy under suitable conditions of environment.